Ann. Rev. Entomol. 1989. 34:139–61

BIOLOGY, HOST RELATIONS, AND EPIDEMIOLOGY OF *SARCOPTES SCABIEI*

Larry G. Arlian

Department of Biological Sciences, Wright State University, Dayton, Ohio 45435

HISTORY OF SCABIES

Scabies is a contagious disease of humans and other mammals. It is caused by the mite *Sarcoptes scabiei*, which burrows in the lower stratum corneum of the skin. Scabies was one of the first diseases in humans with a known cause (41, 85). The Italians Giovanni Cosimo Bonomo and Diancinto Cestoni first described and illustrated the mite in 1689 in a now-famous letter to Francesco Redi (2, 80, 89). However, it was not until 200 years later that scabies was generally accepted as a parasitic disease (85). Endemic and enzootic levels of human and animal scabies, respectively, continue to occur despite the availability of various therapies. Currently, sporadic outbreaks and epidemics in communities (17, 22, 23, 44, 59, 69, 82–85, 91, 94, 102, 119), nursing homes (74, 90), schools (54), hospitals (24, 48, 62, 97), and other institutions (73) and epizootics in wild and domestic animal populations (18, 45, 47, 56, 57, 68, 80, 93, 106, 111) are frequently reported.

Historically, epidemics of human scabies have occurred on a worldwide basis in 30-year cycles with 15-year gaps between them (83, 85). Although many opinions have been given, there is no satisfactory explanation for the significant fluctuations in scabies prevalence. Two notable increases occurred in the last 50 years; one peaked in the mid 1940s, and a second began in the mid to late 1960s on a worldwide basis and in the early 1970s in the United States (25, 69, 70, 83, 85, 87). Scabies sufferers constituted about 2–4% of patients seen by dermatologists in the United States in 1975 (102). The

0066-4170/89/0101-0139$02.00

National Disease and Therapeutic Index for the 12-mo period ending in December 1978 reported approximately one million doctor visits for scabies, a 17-fold increase over 1970 and a threefold increase over the 1974 estimate. The Information Medical Service reported 859,000 visits for scabies in 1983. The increase in scabies in the United States seems to have leveled off, but it has continued at a steady level in the 1980s. Reports from Czechoslovakia (88), Denmark (22), Great Britain (23, 107), India (77, 101), Australia (61), Greece (98), and Africa (110) all called attention to the rise in scabies over the past 20 years. In the United States and most other countries human scabies is not a reportable disease, so it is difficult to know its actual prevalence. However, the above data, coupled with the continued case reports, indicate that scabies is still common. In spite of the latest increase scabies has always been a common disease and more common than was generally supposed. The disease in humans was previously thought to be associated with overcrowding, poverty, and poor hygiene. However, the socioeconomic characteristics of patients with scabies during the recent resurgence in the United States seem to be representative of the overall population (8, 54, 82–85). Studies employing house-to-house survey techniques demonstrated significant scabies prevalence among the middle to high socioeconomic classes and among persons with good hygiene (8, 44, 78). A recent study (8) found that among scabietic patients seen by a dermatologist in southwestern Ohio, 54% of the infested families or individuals were of average socioeconomic level and 33.3% were of above average or high socioeconomic level. Hygienic standards were at least average for both these classes of patients.

A number of studies have reported epizootics or cases of scabies in animals in the last 20 years. Most of these have involved wild canines. Notable epizootics or individual cases of scabies were reported in coyotes in Texas and Kansas (42, 93), coyote–red wolf hybrids in Texas and Louisiana (92), coyotes and wolves in Alberta, Canada (114), red foxes and coyotes in Wisconsin (115), red foxes in Pennsylvania (95), dogs (109), wild canines in New York (111, 112), cattle in New York, Germany, and Denmark (45, 64, 80), mice and peccaries in the New York Zoological Society (68), cats (65, 47), and horses, tapirs, and chamois (55, 57, 59). Hourrigan (53) has outlined the history of scabies in cattle in the United States. Surveys in the United States, New Zealand, Ireland, Australia, and England have shown that 30–35% of the domestic pigs surveyed in some populations were infested with *S. scabiei* (67, 103–105).

Most published information on scabies has focused on the clinical and epidemiological aspects of the disease in humans (reviewed in 2, 86, 87). Several reviews have given an interesting historical perspective and early biological information (41, 49, 76). Until recently, few modern studies had

directly investigated the basic biology of the parasite, the host-parasite interactions, and the host immune and physiological responses to the mite and its products. However, studies along these lines are important to develop a better understanding of the epidemiology of this disease. Therefore, although this chapter reviews some basic biology and clinical aspects of the parasite and the disease, it focuses primarily on experimental studies of the parasite and the host response conducted in the last 10 years.

MORPHOLOGY

Sarcoptes scabiei belongs to the cohort Astigmata (order Acariformes, suborder Sarcoptiformes) (81). *Sarcoptes scabiei* is recognized by the characteristic oval, ventrally flattened, and dorsally convex tortoise-like body, stout dorsal setae, numerous cuticular spines, and transversely ridged cuticular striations. The male (213–285 μm long by 162–210 μm wide) is about two thirds the size of the female (300–504 μm long by 230–420 μm wide) (30). The female exhibits an external copulatory papilla of the bursa copulatrix on the posterior idiosoma anterior to the posterior-dorsal anal opening. The tarsus of legs I and II on females and males and the tibio-tarsus of leg IV of males bear a stalked empodium that terminates in a broad pad. Legs III and IV of females and leg III of males terminate in a long seta. In addition, the tarsus of legs I and II and tibio-tarsus III bear two spur-like claws in both sexes. Tibio-tarsus IV bears one spur-like claw in males and two in females. The anterior stubby legs extend beyond the anterior-lateral margin of the propodosoma, while the posterior legs do not extend beyond the body margin. Five pairs of dorsal setae, five pairs of lateral setae, and anterior pairs of internal and external scapular setae are present on the dorsal surface. The internal scapular setae and the first dorsal and lateral setae are lamellate. Anterior, medial, and posterior genital setae are present in the male; females lack the medial genital setae. Additional descriptive details, in particular of leg chaetotaxy and larval and nymphal stages, can be found in Reference 30.

LIFE CYCLE

Until recently, little was directly known about the life cycle of *S. scabiei;* knowledge was primarily based upon pre–World War II anecdotal observations, principally of *S. scabiei* var. *hominis* (41, 49, 76, 117). A recent in vivo study of the life cycle of *S. scabiei* var. *canis* on a rabbit host, coupled with a detailed morphological study of active and quiescent life stages, for the first time directly revealed that development of both males and females consists of egg, larval, protonymphal, and tritonymphal instars (13, 30). These data are in contrast to several older reports that development consists of

only one nymphal stage in males but of two in females (41, 43, 49, 76, 117). Because the male tritonymph is smaller than the female tritonymph and only slightly larger than the protonymph, this life stage may be confused with the protonymph upon examination with a stereoscope. Protonymphs that eventually become males pass through a small tritonymphal stage. However, protonymphs that give rise to females pass through a larger tritonymphal stage than that of the males. In vivo studies revealed that females are oviparous (13), in spite of a report to the contrary (79).

S. scabiei var. *canis* eggs hatch after a 50–53-hr incubation. Durations of the larval and protonymphal stages are 3.22 ± 1.52 to 4.20 ± 1.52 and 2.33 ± 0.66 to 3.40 ± 0.84 days, respectively. Tritonymphal development requires 2.42 ± 0.51 to 3.42 ± 0.51 days for males and 2.22 ± 1.01 to 3.22 ± 0.97 days for females. Development from egg to adult requires 10–13 days.

It is presumed that the life cycle of *S. scabiei* from other hosts is similar, but this remains to be directly determined. Other aspects of the life history such as fecundity, copulation, the molting process, quiescence, longevity of adults, feeding behavior, and pheromonal activity are still unknown for all scabies strains.

HOST SPECIFICITY AND CROSS-INFESTIVITY

Sarcoptes scabiei infests many different mammalian hosts in 17 families and 7 orders (30). The mites from different hosts exhibit little or no morphological differences; therefore, based on morphology alone, it is unclear if *Sarcoptes* mites associated with different hosts represent different species or simply different varieties of one species. Fain (30, 31) does not consider the variation between strains from different hosts taxonomically significant and proposed that the genus *Sarcoptes* contains only one valid but variable species. Most of the morphological variations among strains from different hosts are in size, the dorsal field of spines, and the ventrolateral spines. For example, most or all specimens from humans exhibit a bare area (lack 1–5 spines) in the dorsal field of spines and lack ventrolateral spines, while those from pigs exhibit a similar dorsal bare area but have ventrolateral spines. Most *S. scabiei* mites that parasitize dogs have no bare area and have ventrolateral spines, while those that parasitize cattle lack ventrolateral spines. Despite similar morphology, *Sarcoptes* mites that parasitize some hosts are recognized as distinct species (56, 57, 59).

Biological evidence indicates that there are physiological differences among scabies mites from different hosts and that scabies mites from different hosts are largely host specific (10, 14, 55, 57, 58). Experimental attempts to transfer scabies from dogs to mice, nude (thymus-deficient) mice, hairless mice, rats, guinea pigs, pigs, cattle, cats, goats, and sheep were unsuccessful

(10, 14). Most of these hosts are known to be parasitized in nature by *S. scabiei*. Scabies from pigs could not be transferred to dogs. However, scabies from dogs could be transferred to New Zealand white laboratory rabbits, although scabies from humans and pigs could not be transferred to the same rabbits (10, 14). These experiments suggest that the transfer of *S. scabiei* from one host species to another does not usually occur. The fact that *S. scabiei* var. *canis* infested the laboratory rabbit while the mites from humans and pigs could not is clear evidence of strain differences. Since the same host rabbits were used in all three cases, the host factors limiting exploitation on the rabbit were identical for the three strains.

Host specificity may be attributed to a number of parasite and host factors and their interactions. The mechanisms for the host specificity of scabies are largely unknown, but specific factors generally do not allow some strains to survive and proliferate for extended periods on strange hosts. Host-recognition and host-seeking stimuli such as odor or body temperature may be involved in host specificity for some strains, but this possibility remains to be investigated for a range of strains. Host odor was not a factor in host specificity for *S. scabiei* var. *canis* in the previously mentioned cross-host transfer experiments (11, 14). When dislodged from a host, this mite was attracted to the odor of cat, rabbit, goat, calf, guinea pig, mouse, and rat (Figure 1), although none of these hosts could be permanently infested (11, 14). Since these mites reside in the host's epidermis, it is probable that some limiting factors and processes are located there. These factors may include physiological differences in the requirements of mite strains; differences in dietary and nondietary properties of the host skin environment; ability of the host to mount an immune response; antigenicity of the parasite, which provokes the immune response in the host; and resistance of the mite to the host immune response.

Humans occasionally become infested with animal scabies strains when they handle or live with infested animals (31, 45, 56, 58, 91, 109, 113). Just how often this occurs is unknown, since the various forms are morphologically similar and not easily distinguished with the usual oil scrape preparations used for clinical diagnosis. The clinical signs of natural and unnatural scabies infestations are identical. Likewise, the extent of cross-infestation between other animals is unknown.

Based on host transfer experiments, most human and animal cross-infestations are probably self-limiting. However, cross-infestations involving animal strains can result in temporary infestations that last several months, during which mites reproduce (Table 1). Transfer experiments indicated that canine mites are capable of burrowing, feeding, and producing eggs in human skin (29). Within 24 hr these infestations produced intense itching and vesicular and pustular lesions around each burrowed mite. These infestations

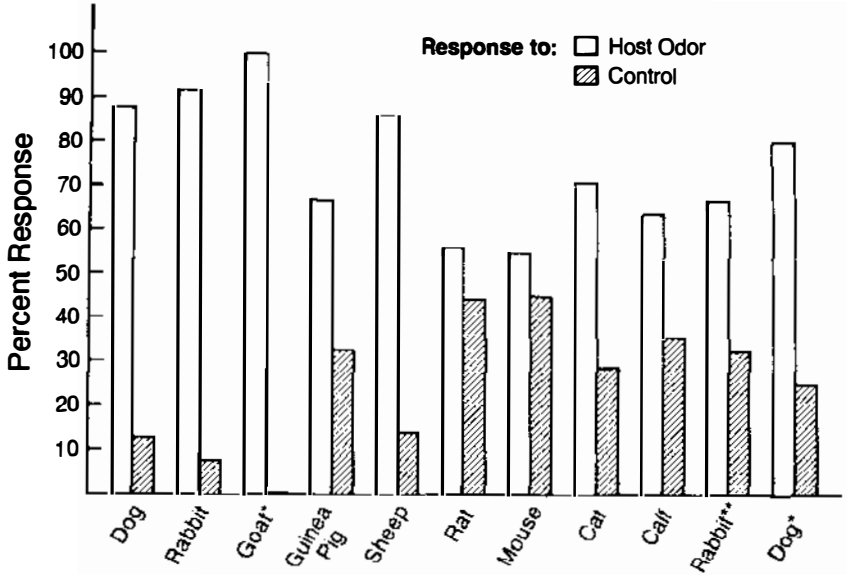

Figure 1 Response of *S. scabiei* var. *canis* after female mites were placed midway between a host odor stimulus and scrubbed air (control). The host odor and control were 5 cm apart except for * = 2 cm and ** = 7 cm.

were temporary and self-limiting. After 1–3 days only dead mites were found in the center of each of these lesions (5).

The ability of strains to develop temporary infestations and reproduce on strange hosts has raised the possibility that temporary hosts may serve as reservoirs for transmission of mites back to natural hosts (14). Self-limiting cross-infestations on some experimentally infested strange hosts lasted up to 13 wk (Table 1). Most of these infestations spread from the point of inoculation as mites reproduced and increasing parasitemia developed. Hosts infested with strange scabies strains exhibited hyperkeratosis similar to that seen in advanced infestations on natural hosts before the infestation gradually waned (14). Transfer of scabies from unnatural hosts back to natural ones may explain apparent treatment failures in domestic animals.

SENSORY PHYSIOLOGY

Sarcoptes scabiei var. *canis* perceives both host odors and thermal stimuli. When dislodged from the host, mites are attracted to the source of these stimuli (11, 14). Likewise, *S. scabiei* var. *hominis* exhibits a strong thermotaxis and moves to the warmest part of a temperature gradient (72). Females of *S. scabiei* var. *canis* placed at varying distances from a rabbit host on a rod

Table 1 Duration of temporary infestations on strange hosts experimentally infested with different strains of *S. scabiei*[a]

Host	*S. scabiei* strain	Duration of infestation
Guinea pig	var. *canis*	51 days
Mouse	var. *canis*	1–2 days
Rat	var. *canis*	6–8 wk
Dog	var. *suis*	2–4 wk
Rabbit	var. *suis*	2–4 wk
Sheep	var. *canis*	1–3 wk
Goat	var. *canis*	10–13 wk
Calf	var. *canis*	5–7 wk
Cat	var. *canis*	8–10 wk
Pig	var. *canis*	4–10 wk

[a]Data from References 10 and 14.

leading to and touching the rabbit migrated toward the host from up to 15.4 cm away (11). More than 63% of the specimens moved toward the host when they were placed at 5.6 cm or less from the rabbit. In these experiments the percentage of test mites moving toward the host increased as the distance was decreased. Within this experimental design, host body temperature, odor, and CO_2 were possible stimuli. Similar experiments in which the host was replaced by a 32°C abiotic thermal stimulus, which eliminated host odor and CO_2 stimuli, gave similar results; 83% of mites placed 5.6 cm from the heat source migrated toward the thermal stimulus. Female mites placed midway between a host and a thermal stimulus at close proximity responded to both with no preference. As the distance between the two stimuli was increased, most mites that responded moved toward the host. Therefore, a combination of host odor and body temperature was a stronger stimulus, or mites perceived odor from a greater distance than temperature alone. Additional experiments showed that all life stages of *S. scabiei* var. *canis* perceived and responded to host odor in the absence of CO_2 (14).

SURVIVAL AND INFESTIVITY

Although it was not directly investigated, the role of fomites in the transmission of human scabies was formerly thought to be minimal (82, 84, 85, 91, 102, 119). However, recent direct studies of the life cycle, behavior, survival, infestivity, and prevalence of mites in the host environment indicates that fomites can be important sources of mites for infestation or reinfestation (8, 9, 11, 13, 14, 16).

Life cycle studies have shown that all life stages frequently leave the burrow and wander on the skin, and they may fall or become dislodged from the host (13). Live mites can be recovered from the environment of scabies patients (8, 9) and presumably from that of other hosts. Survival off the host, coupled with retained infestivity and host-seeking behavior, make it probable that dislodged mites can be important in scabies transmission in homes, barns, outdoor livestock enclosures, and kennels.

Survival off the host is greatly dependent on ambient temperature and relative humidity (RH) (9, 16). Lower temperatures and higher RH, which reduce desiccation, generally favor longer survival, while higher temperatures and lower RH result in significantly reduced survival. Female mites survived only a few hours at 45°C and 25 and 45% RH, but 8 and 19 days at 10°C and 25 and 97% RH, respectively. Females died after 10 min at 50°C; however, those that survived 5 min at this temperature immediately burrowed into the skin when placed back on the host. At the other extreme, some females survived 1 hr at −25°C, but survivors were not infestive and would not penetrate host skin, although they were active and walked about. Therefore, natural or manipulated high or low temperatures could be used to control these mites in the environment.

Generally, all life stages of *S. scabiei* var. *canis* survived 1–9 days at 15–25°C and 25–97% RH. Under comparable conditions males and larvae survived one third to one half as long as other life stages. Tritonymphs of females generally exhibited the longest survival (21 days) of any life stage at 10°C and 97% RH, but they survived only 5–10 hr when survival was determined at 25, 30, 35, and 45°C and 97% RH. Significantly, these mites generally survived 2–5 days at temperature and RH comparable to outdoor summer conditions or those in heated homes and barns. Lower temperatures comparable to winter conditions extended survival.

How long mites retain the ability to penetrate a host (remain infestive) is an important aspect of their survival time off the host. When held off the host at room conditions, *S. scabiei* var. *suis* from pigs burrowed into the skin 24 hr later (9). Likewise, *S. scabiei* var. *canis* that had burrowed in the skin remained infestive 36 hr after the death of the host.

When *S. scabiei* var. *canis* mites were removed from the host, held at 75% RH and 22–24°C for 24 hr, and then placed back on the skin they began burrowing into the skin within 6 min; within 1 hr these specimens were half to fully submerged in the stratum corneum (9, 16). The mean time for complete penetration of these mites was 35.4 ± 17 min. Under these conditions no mites survived 40 hr off the host. Those surviving 36 hr initiated penetration within 3 ± 3 min when placed back on the host, but required 97 ± 36 min to penetrate completely. Nutritional and water requirements stimulated specimens that had been off the host longer to initiate penetration sooner than fresh

specimens. However, because of their weakened condition the time required for complete penetration increased as a function of the time off the host. In addition, live specimens of *S. scabiei* var. *hominis* recovered from the bed linen of scabietic patients penetrated and burrowed when placed on a rabbit. Specimens removed from patients with crusted scabies and held alternately under room conditions (21°C and 45% RH) and refrigeration (4 or 10°C and 95% RH) for 12-hr periods remained infestive and burrowed into rabbit skin after 4 days. These observations and experiments indicate that mites remain infestive for at least one half to two thirds of their survival time when dislodged from the host. By comparison, the average time needed for fresh *S. scabiei* var. *hominis* specimens to initiate penetration was 9.6 ± 6.2 min, and these specimens were completely submerged in 31.0 ± 15.0 min. Fresh females of *S. scabiei* var. *canis* initiated penetration within 20.5 ± 16.5 min and required 23 ± 5.9 min after initial penetration to become completely submerged in the stratum corneum. Males, nymphs, and larvae of *S. scabiei* var. *canis* penetrate and become completely submerged in the skin in less time than females (9). Larvae, compared with other life stages, complete penetration most rapidly (Table 2).

PREVALENCE OF SCABIES IN THE HOST ENVIRONMENT

Only a few studies have directly investigated the occurrence of scabies mites in the environment of scabietic patients (8, 9, 21, 51). In detailed studies of the home environment of 37 scabietic patients, 44% of the homes contained scabies mites in the dust vacuumed from floors, overstuffed chairs or couches, and mattresses (8). Dust samples from 64% of the positive homes contained live mites. Live mites were most often recovered from bedroom floors and chairs or couches. Some dust samples were not analyzed until 72 hr after collection; the prevalence of live mites would likely have been higher had the dust samples been analyzed immediately upon collection. The recov-

Table 2 Time required for *S. scabiei* var. *canis* to penetrate the skin of a rabbit host[a]

Life stage	Time required to penetrate (min)	Number tested
Female	43.5	17
Male	21.2	19
Nymph	16.8	18
Larva	11.1	18

[a]Data from Reference 9.

ery of live mites from the homes of scabietic patients, coupled with mite survival of 1–5 days at room conditions (9, 16), the host-seeking behavior of all life stages (11, 14), and the mite's rapid penetration of the host's skin once on the host (9), indicates that fomites in homes can be a source for transmission.

Interestingly, detailed study of the environment of nursing homes housing scabietic patients gave different results (8). Live mites were less frequently recovered from bedding, floors, and furniture than in patient homes. Regular housekeeping practices, frequent bed linen changes, and stringent hygienic standards in the nursing homes studied minimized fomite contamination, and higher room temperatures resulted in higher mite mortality due to desiccation. Personal contact was probably the primary means of transmission among patients, staff, and family members in these nursing homes.

HOST/PARASITE ENERGETICS

Few studies have quantitated the effects of scabies infestations on the health, weight, and physiology of parasitized animals. Lightly infested hosts usually do not exhibit obvious disease manifestations. Chronic and severe scabies infestations cause visible deterioration of the host's physical condition, progressive emaciation or reduced weight gain in growing animals, reduced milk production in cattle, and eventually even death (3, 6, 7, 20, 80, 93, 103). These signs may be accompanied by changes in specific serology and blood biochemistry in some hosts, depending upon the host species and the duration and severity of the infestation (6, 93). The reasons for weight changes, altered physiology, and death are unknown.

These mites directly drain energy from the host by consuming the host's lymph and lysed tissue. Indirectly, host energy is drained by the mite-stimulated hyperplasia and the subsequent loss of stratum corneum and by increased physical activity caused by response to the parasitic infestation. Study of the energetics of rabbits parasitized by *S. scabiei* var. *canis* has shown that even under heavy parasitemia mites do not deplete sufficient energy from the host to account for the weight loss or reduced weight gain of heavily parasitized hosts (7). Mite density at the crusted stratum corneum/stratum lucidum interface of heavily parasitized rabbits was about 1483 mites per cm^2 (7). A typical mite population on this host comprised 18% females, 18% males, 13% female tritonymphs, 24% protonymphs and male tritonymphs combined, and 27% larvae. Measured O_2 consumption at 34°C and 75% RH for female and male *S. scabiei* was 2 and 0.76 nl O_2 per hr per mite, respectively. Based on proportional size and activity, nymphs and larvae utilized an estimated 0.76 and 0.38 nl O_2 per hr per mite, respectively. With this mite density and these O_2 requirements, it has been estimated that the mite population would utilize 150.48 μl O_2 per day per cm^2 of infested

surface. Since 1 μl O_2 consumed corresponds to approximately 0.0048 cal derived through metabolism of food, 0.722 cal per day per cm^2 was obtained from the host. This amount was only 0.25–0.40% of the host's daily metabolism. Based on weight gain by matched uninfested control rabbits, mite consumption reduced the weekly weight gain of growing rabbits by only 1.9%, or less than 0.01 g of host biomass (carbohydrate, fat, or protein) per wk. Clearly, direct energy drain does not cause reduced weight gain or weight loss in heavily parasitized animals (7). Indirect energy drains, i.e. the hyperplasia and loss of stratum corneum that may accompany heavy infestations, are probably much more significant.

Controlled laboratory experiments demonstrated that during development of a scabies infestation, young rabbits grew at a rate comparable to that of noninfested control rabbits during the first 17 wk of infestation. However, infested rabbits consumed more food than controls, which indicates a lower food-converting efficiency. As the infestation spread and parasitemia became heavy, growth of the rabbits stopped abruptly. A steady weight loss occurred over the next 25 wk until the rabbits were treated. Control rabbits continued to grow. Interestingly, food consumption by infested rabbits during the period of weight loss was similar to that of controls. Therefore, for unknown reasons, food-converting efficiency was much reduced. Two similar studies reported that weight gains in young pigs parasitized by *S. scabiei* were reduced by 3.3 and 5.5% when compared to gains of noninfested controls (3,20). However, the infested pigs of the Cargill & Dobson study (20) showed depressed food efficiency, whereas those in the study of Alva-Valdes et al (3) showed no significant difference compared with the controls. By contrast, another study reported that pigs lightly infested with *S. scabiei* responded similarly to parasitized rabbits in that the infestation had no significant effect on growth (103, 106). Unlike the rabbits, the pigs showed no change in food-converting efficiency.

Although data are limited, it generally appears that light infestations have little effect on the growth rate of young hosts, but the food-converting efficiency may or may not be influenced. In chronic heavy scabies infestations weight is affected. It is unknown what causes the reduced weight. Reports of pathophysiology in infested hosts suggest that toxic secretions from the mite, coupled with the host's immune responses and possibly with secondary bacterial infections, contribute to disease manifestations (5, 6, 93, 104, 105).

PATHOPHYSIOLOGY

Animals with chronic heavy scabies infestations exhibit varied changes in serology and blood biochemistry. Parasitized rabbits and pigs develop anemia as evidenced by significantly reduced hemoglobin, hematocrit, and mean

corpuscular hemoglobulin levels (6, 103). Sheahan (103) suggested that in pigs the anemia was related to an iron deficiency caused by loss of iron in shed skin scales and reduced ability to absorb iron from the intestine. Reduced serum iron concentrations in human patients with scaly dermatoses have been reported (66, 108). Rabbits exhibited highly variable serum iron levels, but although they were lower than those of controls, they were not statistically different. Whether or not there is a relationship between anemia caused by scabies infestation and dietary iron deficiency, altered iron absorption, or iron metabolism is still unknown. Dogs and rabbits provided ad lib complete diets in the laboratory and both iron-treated and iron-deprived pigs developed severe scabietic lesions, which suggests that dietary iron deficiency does not predispose to scabies. However, the iron-deprived pigs of the Sheahan study (103) showed significantly reduced weight gains and lower hematological values, which had no apparent relationship to the severity of the scabietic lesions. These data indicate that iron deprivation may not affect susceptibility but that it does affect severity of anemia and expression of pathological manifestations (possibly by increasing the iron requirements). In contrast, Kutzer (55) considers dietary vitamin A and mineral supplies to be important factors in predisposition to scabies. One study reported that blood hematocrit, hemoglobin, and total serum protein levels in cattle moderately or severely infested with *S. scabiei,* in contrast to those in rabbits and pigs, were normal (80).

Two studies have examined in detail selected hematological and blood biochemical parameters usually used as prognostic indicators of disease in infested and uninfested hosts. Abnormal values in some of these parameters indicated that scabies causes pathological conditions in severely infested hosts (6, 93). Similar neutrophil, lymphocyte, monocyte, eosinophil, and basophil levels in scabies-infested and uninfested wild coyotes have been reported (93). Interestingly, infested humans show blood eosinophilia (37). By contrast, scabies-infested laboratory rabbits exhibited elevated neutrophil levels and reduced lymphocyte, eosinophil, and basophil levels (6). The reduced levels in rabbits may reflect cell migration to the infested dermal/epidermal area and sequestering of B cells in lymphoid tissue. Generally, deviant serum biochemical parameters that accompanied the infestation in both rabbit and coyote hosts were similar except that total serum protein was elevated in rabbits and reduced in coyotes; glucose and alkaline phosphatase were normal in rabbits but reduced in coyotes; blood urea nitrogen (BUN) was reduced in rabbits and elevated in coyotes; and bilirubin was normal in rabbits and elevated in coyotes (Table 3). Slightly and moderately infested rabbits and coyotes showed fewer or no deviations in blood chemistry levels. These indexes return to normal in rabbits following treatment and recovery, which indicates that the pathophysiological conditions that develop as a result of

Table 3 Serum biochemical parameters for *S. scabiei* var. *canis*–infested rabbits (6) and coyotes (93)

Serum biochemistry	Mean value infested host relative to control	
	Rabbit	Coyote
Total protein	Elevated	Reduced[a]
Total globulins	Elevated	
Alpha globulins	—	Reduced
Gamma globulins	—	Elevated
Albumin	Reduced	Reduced
Albumin/globulin ratio	Reduced	Reduced[a]
Triglycerides	Elevated	
Cholesterol	Normal[b]	
Glucose	Normal[b]	Reduced[a]
Blood urea nitrogen (BUN)	Reduced	Elevated
Creatinine	Reduced	Reduced[a]
BUN/creatinine ratio	Normal[b]	
Uric acid	Normal	—
Lactic acid dehydrogenase	Normal[b]	Elevated
Glutamic oxaloacetic transaminase	Normal[b]	—
Total bilirubin	Normal	Elevated[a]
Gamma glutamyltransferase	Reduced[b]	
Glutamic pyruvic transaminase	Reduced	-
Alkaline phosphatase	Normal[b]	Reduced
Iron	Reduced[a]	—
Calcium	Reduced	Reduced
Phosphorus	Normal	Elevated[a]
Sodium	Normal	-
Potassium	Normal	-
Chloride	Elevated	—
Creatinine phosphokinase	—	Reduced

[a]Not reported as significant.
[b]Some individuals significantly different from controls.

scabies infestation are reversible. Sheahan (104, 105) has also reported significant increases in mean total serum protein and beta and gamma globulins in infested pigs. These pigs also exhibited large deposits of glycogen and acid mucopolysaccharide in the scabietic lesions.

CLINICAL SCABIES

The usual signs and symptoms of human scabies infestations are pruritic, erythematous, papular, and vesicular lesions that are associated with the burrowed mite. Some children may develop nodular scabies, which is characterized by reddish-brown infiltrated nodules that may persist for months

despite therapy (85). In some patients an additional rash with numerous small mite-free urticarial papules develops on other mite-free areas of the body (37, 46, 63, 99). The cause of these secondary lesions is unknown, but it has been suggested that they result from an allergic sensitivity or autosensitization reaction that is due to either cell-mediated immune responses or circulating immune complexes (46, 63). Itching associated with the mite may be mild to severe, and it is reported by many to be most noticeable at night (2). It is not clear if the nighttime intense itching is due to increased body sensitization during that time, increased mite activity (burrowing and associated secretions and defecation), or simply an increased awareness of discomfort in a resting individual. Metabolic studies of *S. scabiei* off the host have shown that there are no intrinsic diurnal changes in mite O_2 consumption that would reflect changes in activity (7). However, on the host, diurnal changes in the host's physiology could act as extrinsic stimuli to prompt parallel changes in mite activity.

In humans, mites and lesions most often tend to localize in the webs of the fingers, the volar aspect of the wrists and arms, and the extensor aspect of the elbows (2, 25, 69–71). Other areas commonly involved, in order of declining frequency, are the soles and insteps of the feet, genitals, buttocks, axillae, waistline, and the area around the nipples (2, 25, 69). It is not clear what characteristics of the skin direct infestation to these body areas. In humans, the clinical signs and symptoms of early to moderate stages of scabies infestation mimic other skin diseases such as dermatitis, herpetiformis, eczema, syphilis, impetigo, furunculosis, papular urticaria, allergic reactions, and response to other ectoparasitic mites and insects (e.g. chiggers, *Pyemotes* spp., lice, fleas, and bedbugs) (2, 19, 26).

The severe itching and associated lesions of a primary infestation are generally reported to take 4–8 wk to develop (70). Therefore, the disease is usually not diagnosed until long after the patient's contact with scabies. This latent period of primary infestation is thought to be associated with the development of sensitization. However, with subsequent reinfestations (secondary infestations) sensitization and similar signs and symptoms are evident within 24–48 hr and develop rapidly, presumably because the host has been sensitized by the previous infestation (70). A few recent reports have indicated that lesions and the associated pruritus of primary infestations have developed within a few days to 2 wk in some cases (62, 90, 97). The reason for this accelerated development is unknown. It may be associated with these scabies patients' previously developed sensitivity to the house dust mite (15, 75). It has recently been discovered that some antigens of scabies and house dust mites are cross-reactive, and atopic patients with dust mite sensitivity and no history of scabies exhibit circulating IgE directed at determinants of *S. scabiei* antigens (15). On the other hand, it is interesting that primary (temporary) canine scabies in humans exhibits pruritic, erythematous vesicular

lesions within 24–36 hr. The rapid skin reaction of humans to *S. scabiei* var. *canis* and the generally more delayed skin reaction to *S. scabiei* var. *hominis* indicate that there are antigenic differences between the two strains.

Mites produce a serpiginous burrow in the stratum corneum as they digest and consume this tissue. This burrow is frequently described as a clinical sign for the diagnosis of scabies. Unfortunately, in most hosts these burrows are rarely visible with the unaided eye or without enhancement. Generally they are only visible when there is sufficient inflammation associated with the burrow and the accumulation of ingrained dirty material. They are always present, however, and they may be made visible by placing a drop of ink on or rubbing an ink pen over the suspected skin (120). After a few minutes ink will seep into the burrow, and when the excess is wiped from the skin surface the ink-filled burrow will be clearly visible. The burrow is also enhanced by applying liquid tetracycline (27). The burrows then fluoresce bright yellow-green under a Woods light.

The clinical skin signs of scabies infestation are similar for most mammals except that in some hosts mite proliferation and thus progression of the disease is more rapid than in others. For example, experimental inoculation of a small area on the back of a dog led to total body involvement and localized hyperkeratosis in 3–4 wk (10). By comparison, similar inoculation of rabbits with *S. scabiei* var. *canis* resulted in full body involvement and localized hyperkeratosis with crusting only after many months. Likewise, humans develop localized regions of hyperkeratosis and full body involvement only after many months with infestations of *S. scabiei* var. *hominis*.

Untreated scabies in all mammals advances to scaly skin and eventually heavy crusting from hyperkeratosis. The crusted state in humans is referred to as Norwegian scabies. Hyperkeratotic crusts in humans and animals vary in thickness from a few to 20 mm. Crusts are dry and porous with numerous vacant mite burrows (10, 116). Crusts can be readily pried off the host. Mites are found on the undersurface of the crusts at the moist interface of the stratum corneum/stratum lucidum and the stratum granulosum of the epidermis. Mite density at this interface may exceed 1400 mites per cm^2 of skin surface (7).

Scabies is indisputably diagnosed in all hosts by positive skin scrapings. Suspected areas are scraped with a scalpel or razor blade, and the removed epidermis is placed on a microscope slide in a drop of mineral oil and then overlaid with a coverslip. Eggs, all active life stages, fecal pellets, and in some cases partial or complete burrows are visible under both the dissecting and compound microscopes.

SCABIES ANTIGENS

Scabies mites reside in the lower stratum corneum of the epidermis near the stratum corneum/stratum lucidum interface (28, 29). Histological, nutritional,

and water-procurement studies suggest that intercellular fluid from lower skin zones may seep into the burrows or at least into close proximity of the burrowed mites and their mouthparts. Apparently this aqueous material provides a medium for soluble antigens (presumably from the mite's body), saliva and other body secretions, and feces to diffuse into the dermis and stimulate an inflammatory and immune response. As yet little is known about the specific source and properties of these antigens for most scabies strains. Until recently the inadequate supplies of scabies mites and antisera against them limited investigations both to characterize scabies antigens and to determine the host immune response to them. However, the recently reported successful transfer of *S. scabiei* var. *canis* to laboratory rabbits has provided an adequate supply of mites for preparation of antigenic extracts and antiscabies sera for immunologic study (10, 12). Using this rabbit model, antigens of *S. scabiei* var. *canis* have been partially characterized by crossed immunoelectrophoresis (CIE), crossed radioimmunoelectrophoresis (CRIE), and SDS-PAGE coupled with Western blotting and autoradiography (12, 15).

CIE of *S. scabiei* var. *canis* extract reacted with antisera from rabbits heavily parasitized with this strain demonstrated the presence of nine antigens; seven antigens were anodically moving (electronegative) and two were cathodically moving (electropositive) (12, 15). Fractionation of *S. scabiei* var. *canis* extract by SDS-PAGE resolved more than 30 protein/peptide bands (15). At least 20 bands were in the 14–66 kd range. Following blot transfer of the protein bands onto nitrocellulose membranes and incubation of individual tracks in human allergic reference sera and radiolabeled anti-human IgE, autoradiograms showed that 15 different protein/peptide bands bound IgE antibodies. Since nine antigens were identified by CIE but 15 SDS-PAGE–resolved bands bound human IgE, some of the antigens must exhibit multiple antigenic determinants. It is not known if multiple determinants on a single antigen are similar or different. The finding that determinants of *S. scabiei* antigens bind human IgE is significant, since IgE is the antibody type associated with allergic disease.

Preliminary indirect immunologic evidence indicated at least some cross-antigenicity between antigens of *S. scabiei* strains from different hosts (15). At least two antigen-antibody precipitates formed by CIE reaction of antigens of *S. scabiei* var. *canis* extract with anti–*S. scabiei* var. *canis* rabbit sera following incubation of CIE gels in scabietic (*S. scabiei* var. *hominis*) patient sera exhibited IgE binding. The fact that patients infested with *S. scabiei* var. *hominis* exhibited circulating IgE antibodies that bound to antigens of *S. scabiei* var. *canis* is direct evidence (provided that this binding was not cross-reactivity involving house dust mites) that there is at least partial, if not complete, identity between antigens of these strains. Falk et al (36) reported that rabbit antiserum raised against the house dust mite *Dermatophagoides*

farinae recognized four *S. scabiei* var. *hominis* antigens. By comparison, anti–*D. farinae* rabbit serum recognized six *S. scabiei* var. *canis* antigens (15). These results are indirect evidence that the *S. scabiei* strains from dogs and humans may share at least four antigens or epitopes that cross-react with house dust mite antigens (15). Direct investigations of the similarities and differences in antigenicity of scabies from different hosts are still necessary to establish clearly the immunologic relationships among strains and their implications.

CELL-MEDIATED IMMUNE RESPONSE

The cell-mediated host immune response to scabies antigens is characterized by cell infiltrates in or near the skin lesions. These infiltrates may be in the superficial and deep dermis, in tissue surrounding small blood vessels, around sweat glands in the lower dermis, and in subcutaneous fat (1, 37–39, 50). They consist of mainly lymphocytes and fewer histocytes, neutrophils, and eosinophils (37). The density of the infiltrates varies according to the level of infestation and varies among lesions, but the predominant lymphocytes in the infiltrates are T lymphocytes (38). The fact that the ratio of T lymphocytes to B lymphocytes is greater in the infiltrates than in peripheral blood reflects selective movement of T cells into the dermis (38). T lymphocytes have a major role in delayed hypersensitivity skin reactions. Their accumulation in the dermis suggests that this type of reaction occurs in scabies, and their accumulation in lesions shows the importance of a cell-mediated immune response in the pathogenesis of scabies (38). Prick and intracutaneous skin testing of patients within a year after scabies infestation indicated that immediate hypersensitivity reactions may occur (35).

Scabies-infested pigs developed immediate and delayed hypersensitivity reactions following local inoculation with a crude extract of *S. scabiei* (105). The immediate reaction resembled a local anaphylactic response. Interestingly, iron-deprived pigs reacted less to the intradermal inoculation than iron-treated littermates. These reactions appeared similar to reactions in human skin.

HUMORAL IMMUNE RESPONSE

It is clear that scabies antigens provoke a humoral immune response. However, few controlled studies have investigated and thoroughly characterized this response for any host. Both immunized and naturally infested rabbits, pigs, and guinea pigs exhibit serum antibodies directed at *S. scabiei* antigens (12, 15, 104, 118, 121, 122). Direct reaction of *S. scabiei* var. *canis* extract by CIE with sera from scabies-infested rabbits demonstrated that the rabbits built

antibodies to nine different antigens (12). Varied alterations in serum isotypic immunoglobulin levels in scabietic patients relative to posttreatment levels or levels in serum of uninfested patients have provided indirect evidence of a humoral response in humans. Hancock et al (46) reported that circulating IgA levels may be significantly lower in scabies patients than in normal persons. Likewise, Falk (32, 33) found that IgA levels of scabietic patients were significantly lower than those of the same patients 6 and 9 mo later following successful treatment. Elevated serum IgG and IgM levels in scabietic patients, which returned to normal following treatment, have also been reported (32).

Investigations of serum IgE levels of scabietic patients give conflicting evidence of whether or not scabies antigens provoke an IgE-mediated reaction to scabies. Hancock et al (46) found that 99 of 100 patients examined in a study had total IgE levels within normal limits. By contrast, Araujo-Fontaine et al (4), Falk (32), Falk & Bolle (34, 35), and Larregue et al (60) found elevated IgE values in 15, 20, 42, 45, and 65% of their patients, respectively. Since specific scabies antigens were not used as probes in these studies, it was not known if IgE was induced by scabies antigens or was the result of atopy. Most of the patients in Falk's study (32) had no obvious history of atopy, but their histories were not confirmed. Two more recent studies using scabies extracts have directly demonstrated *S. scabiei*–specific IgE in scabietic sera, but the number of patients examined was small (5, 96).

Since these initial immunologic investigations of scabietic patient sera, understanding of the antibody response to scabies antigens has become even more uncertain with the recent finding that scabies and house dust mites are highly cross-antigenic; the IgE built against *D. farinae* recognizes antigenic determinants on *S. scabiei*. Because of this cross-reactivity and the lack of human studies with patients skin-tested to house dust mites, the IgE and other isotypic responses to scabies have not yet been confirmed.

Apparently, mite antigens promote selected diffusion of circulating antibodies and C3 complement out of the vasculature and their deposition in dermal vessels, epidermis, and the dermoepidermal junction in the vicinity of the mites. Immunofluorescence studies of biopsied specimens from involved skin of 11 patients revealed IgE in vessel walls from four patients, IgM and C3 deposits at the dermoepidermal junction in one patient, and only C3 deposits in the latter area in one patient (40). Deposits of IgG, IgM, and C3 in dermal vessels and IgG, IgA, and C3 at the dermoepidermal junction have also been noted in similar studies (52, 100). The biological importance of these responses in determining host susceptibility and resistance to scabies infestations and host specificity remain to be determined. Variations in resistance and susceptibility in natural hosts as well as host specificity may reflect both differences in the hosts' ability to mount these responses and the parasites' resistance to them.

SUMMARY

Scabies continues to be an important parasitic disease of humans and other mammals. Surprisingly for a disease that has afflicted humans since antiquity, little is directly known about the basic biology of the parasite, the host-parasite interactions, the host immune response, and host susceptibility. Much more research in these areas is needed if we are to understand fully the occurrence, transmission, and epidemiology of both human and animal scabies.

ACKNOWLEDGMENTS

Much of the research in this review was supported by grant No. AI 17252 from the National Institute of Allergy and Infectious Diseases.

I express my thanks to D. L. Vyszenski-Moher for editorial assistance during preparation of the manuscript.

Literature Cited

1. Ackerman, A. B. 1977. Histopathology of human scabies. See Ref. 87, pp. 88–95
2. Alexander, J. O. 1984. Scabies. *Arthropods and Human Skin,* pp. 227–92. Berlin: Springer-Verlag. 422 pp.
3. Alva-Valdes, R., Wallace, D. H., Foster, A. G., Ericsson, G. F., Wooden, J. W. 1986. The effects of sarcoptic mange on the productivity of confined pigs. *Vet. Med.* 81(3):258–62
4. Araujo-Fontaine, A., Thiery, R., Heid, E. 1977. Serum IgE levels in scabies; studies of about 100 cases. *Ann. Dermatol. Venereol.* 104:203–5
5. Arlian, L. G. 1988. Host-parasite interaction of *Sarcoptes scabiei.* In *Progress in Acarology,* ed. G. P. Channa-Basavanna, B. K. Negeshchandra. New Delhi: Oxford & IBH. In press
6. Arlian, L. G., Ahmed, M., Vyszenski-Moher, D. L. 1988. Effects of *S. scabiei* on blood indexes of parasitized rabbits. *J. Med. Entomol.* 25:In press
7. Arlian, L. G., Ahmed, M., Vyszenski-Moher, D. L., Estes, S. A., Achar, S. 1988. Energetic relationships of *Sarcoptes scabiei* var. *canis* with the laboratory rabbit. *J. Med. Entomol.* 25:57–63
8. Arlian, L. G., Estes, S. A., Vyszenski-Moher, D. L. 1988. Prevalence of *Sarcoptes scabiei* in the environment of scabietic patients. *J. Am. Acad. Dermatol.* 19(5):In press
9. Arlian, L. G., Runyan, R. A., Achar, S., Estes, S. A. 1984. Survival and infestivity of *Sarcoptes scabiei* var. *canis* and var. *hominis. J. Am. Acad. Dermatol.* 11:210–15
10. Arlian, L. G., Runyan, R. A., Estes, S. A. 1984. Cross-infestivity of *Sarcoptes scabiei. J. Am. Acad. Dermatol.* 10: 979–86
11. Arlian, L. G., Runyan, R. A., Sorlie, L. B., Estes, S. A. 1984. Host-seeking behavior of *Sarcoptes scabiei. J. Am. Acad. Dermatol.* 11:594–98
12. Arlian, L. G., Runyan, R. A., Sorlie, L. B., Vyszenski-Moher, D. L., Estes, S. A. 1985. Characterization of *Sarcoptes scabiei* var. *canis* (Acari: Sarcoptidae) antigens and induced antibodies in rabbits. *J. Med. Entomol.* 22:321–23
13. Arlian, L. G., Vyszenski-Moher, D. L. 1988. Life cycle of *Sarcoptes scabiei* var. *canis. J. Parasitol.* 74:427–30
14. Arlian, L. G., Vyszenski-Moher, D. L., Cordova, D. 1988. Host specificity of *S. scabiei* var. *canis* and the role of host odor. *J. Med. Entomol.* 25:52–56
15. Arlian, L. G., Vyszenski-Moher, D. L., Gilmore, A. M. 1988. Cross-reactivity of *Sarcoptes scabiei* and the house dust mite, *Dermatophagoides farinae. J. Med. Entomol.* 25:240-47
16. Arlian, L. G., Vyszenski-Moher, D. L., Pole, M. J. 1988. Survival of adults and developmental stages of *Sarcoptes scabiei* var. *canis* when off the host. *Exp. Appl. Acarol.* In press
17. Blumenthal, D. S., Taplin, D., Schultz,

M. G. 1976. A community outbreak of scabies. *Am. J. Epidemiol.* 104:667–72
18. Brownlie, W. M:, Harrison, I. R. 1960. Sarcoptic mange in pigs. *Vet. Rec.* 72:1022–23
19. Busvine, J. R. 1977. Dermatoses due to arthropods other than the scabies mite. See Ref. 87, pp. 132–38
20. Cargill, C. F., Dobson, K. J. 1979. Experimental *Sarcoptes* infestations in pigs: (2) Effects on production. *Vet. Rec.* 104:33–36
21. Carslaw, R. W., Dobson, R. M., Hood, A. J. K., Taylor, R. N. 1975. Mites in the environment of cases of Norwegian scabies. *Br. J. Dermatol.* 92:333–37
22. Christophersen, J. 1978. The epidemiology of scabies in Denmark, 1900–1975. *Arch. Dermatol.* 114:747–50
23. Church, R. E., Knowelden, J. 1978. Scabies in Sheffield: a family infestation. *Br. Med. J.* 1:761–63
24. Cooper, C. L., Jackson, M. M. 1986. Outbreak of scabies in a small community hospital. *Am. J. Infect. Control* 14: 173–79
25. Epstein, E., Orkin, M. 1985. Scabies: clinical aspects. See Ref. 86, pp. 19–22
26. Estes, S. A. 1978. Scabies: the diagnostic dilemma. *Ariz. Med.* 35:477–79
27. Estes, S. A. 1982. Diagnosis and management of scabies. *Med. Clin. North Am.* 66:955–63
28. Estes, S. A., Arlian, L. G. 1984. Reply. *J. Am. Acad. Dermatol.* 10:676–77
29. Estes, S. A., Kummel, B., Arlian, L. G. 1983. Experimental canine scabies in humans. *J. Am. Acad. Dermatol.* 9:397–401
30. Fain, A. 1968. Etude de la variabilité de *Sarcoptes scabiei* avec une revision des Sarcoptidae. *Acta Zool. Pathol. Antverp.* 47:1–196
31. Fain, A. 1978. Epidemiological problems of scabies. *Int. J. Dermatol.* 17: 20–30
32. Falk, E. S. 1980. Serum immunoglobulin values in patients with scabies. *Br. J. Dermatol.* 102:57–61
33. Falk, E. S. 1981. Serum IgE before and after treatment for scabies. *Allergy* 36: 167–74
34. Falk, E. S., Bolle, R. 1980. IgE antibodies to house dust mite in patients with scabies. *Br. J. Dermatol.* 102:283–88
35. Falk, E. S., Bolle, R. 1980. In vivo demonstration of specific immunological hypersensitivity to scabies mite. *Br. J. Dermatol.* 103:367–73
36. Falk, E. S., Dale, S., Bolle, R. Haneberg, B. 1981. Antigens common to scabies and house dust mites. *Allergy* 36:233–38
37. Falk, E. S., Eide, T. J. 1981. Histologic and clinical findings in human scabies. *Int. J. Dermatol.* 20:600–5
38. Falk, E. S., Matre, R. 1982. In situ characterization of cell infiltrates in the dermis of human scabies. *Am. J. Dermatopathol.* 4:9–15
39. Fernandez, N., Torres, A., Ackerman, B. 1977. Pathologic findings in human scabies. *Arch. Dermatol.* 113:320–24
40. Frentz, G., Veien, N. K., Eriksen, K. 1977. Immunofluorescence studies in scabies. *J. Cutaneous Pathol.* 4:191–93
41. Friedman, R. 1947. *The Story of Scabies,* Vol. 1. New York: Froben. 468 pp.
42. Gier, H. T., Kruckenberg, S. M., Marler, R. J. 1978. Parasites and diseases of coyotes. In *Coyotes, Biology, Behavior, and Management,* ed. M. Bekoff, pp. 37–69. New York: Academic. 384 pp.
43. Gordon, R. M., Lavoipierre, M. M. J. 1962. *Entomology for Students of Medicine.* Oxford: Blackwell. 258 pp.
44. Gulati, P. V., Braganza, C., Singh, K. P., Borker, V. 1977. Scabies in a semi-urban area of India: an epidemiologic study. *Int. J. Dermatol.* 16:594–98
45. Haarløv, N., Møller-Madsen, M. 1982. Sarcoptid mange in a Danish cattle herd. In *Acarology VI,* ed. D. A. Griffith, C. E. Bowman, 2:1138–42. West Sussex, England: Horwood. 1296 pp.
46. Hancock, B. W., Ward, A. M., Path, M. R. C. 1974. Serum immunoglobulin in scabies. *J. Invest. Dermatol.* 63:482–84
47. Hawkins, J. A., McDonald, R. K., Woody, B. J. 1987. *Sarcoptes scabiei* infestation in a cat. *J. Am. Vet. Med. Assoc.* 190:1572–73
48. Haydon, J. R., Caplan, R. M. 1971. Epidemic scabies. *Arch. Dermatol.* 103: 168–73
49. Heilesen, B. 1946. Studies on *Acarus scabiei* and scabies. *Acta Derm.-Venereol. Suppl.* 26:1–370
50. Hejazi, N., Mehregan, A. H. 1975. Scabies: histological study of inflammatory lesions. *Arch. Dermatol.* 111:37–39
51. Hewitt, M., Barrow, G. I., Miller, D. C., Turk, F., Turk, S. 1973. Mites in the personal environment and their role in skin disorders. *Br. J. Dermatol.* 89: 401–9
52. Hoefling, K. K., Schroeter, A. L. 1980. Dermatoimmunopathology of scabies. *J. Am. Acad. Dermatol.* 3:237–40
53. Hourrigan, J. L. 1979. Spread and de-

tection of psoroptic scabies of cattle in the United States. *J. Am. Vet. Med. Assoc.* 175:1278–80
54. Juranek, D. D., Schultz, M. G. 1977. Epidemiologic investigations of scabies in the United States. See Ref. 87, pp. 64–72
55. Kutzer, E. 1966. Zur Epidemiologie der *Sarcoptes*räude. *Angew. Parasitol.* 7: 241–48
56. Kutzer, E. 1970. Merkblätter über angewandte Parasitenkunde und Schädlingsbekämpfung, Merkblatt Nr 17. *Sarcoptes*-Milben und *Sarcoptes*räude der Haustiere. Beilage zu. *Angew. Parasitol.* 11:1–22
57. Kutzer, E., Grünberg, W. 1967. Sarcoptesräude (*Sarcoptes tapiri* nov. spec.) bei Tapiren (*Tapirus terrestris* L.). *Z. Parasitenkd.* 29:46–60
58. Kutzer, E., Grünberg, W. 1969. Zur frage der übertragung tierischer Sarcoptesräuden auf den Menschen. *Berl. Münch. Tierärztl. Wochenschr.* 82:311–14
59. Kutzer, E., Onderscheka, W. 1966. Die Räude der Gemse und ihre Bekämpfung. *Z. Jagdwiss.* 12:63–84
60. Larregue, M., Gombert, P., Levy, C., Gallet, P., Rat, J. P. 1976. Elevation des IgE dan la gale chez l'enfant. *Bull. Soc. Fr. Dermatol. Syphiligr.* 83:54
61. Lee, D. J. 1971. High incidence of scabies. *Med. J. Aust.* 2(9):500–1
62. Lerche, N. W., Currier, R. W., Juranek, D. O., Baer, W., Dubay, N. 1983. Atypical crusted "Norwegian" scabies: report of nosocomial transmission in a community hospital and an approach to control. *Cutis* 31:637–84
63. Levene, G. M., Turk, J. L. 1970. Immunological aspects of skin disease. *Br. J. Hosp. Med.* 3:811–18
64. Liebisch, A., Petrich, J. 1977. Zur gegenwärtigen Verbreitung und Bekämpfung der Rinderräude in Norddeutschland. *Dtsch. Tierärztl. Wochenschr.* 84:424–27
65. Lindquist, W. D. 1973. Sarcoptic mange in a cat. *J. Am. Vet. Med. Assoc.* 162:639–40
66. Marks, J., Shuster, S. 1968. Iron metabolism in skin disease. *Arch. Dermatol.* 98:469–75
67. McPherson, E. A. 1960. Sarcoptic mange in pigs. *Vet. Rec.* 72:869–70
68. Meierhenry, E. F., Clausen, L. W. 1977. Sarcoptic mange in collared peccaries. *J. Am. Vet. Med. Assoc.* 71: 983–84
69. Mellanby, K. 1977. Epidemiology of scabies. See Ref. 87, pp. 60–63
70. Mellanby, K. 1977. Scabies in 1976. *R. Soc. Health J.* 97:32–36
71. Mellanby, K. 1985. Biology of the parasite. See Ref. 86, pp. 9–18
72. Mellanby, K., Johnson, C. G., Bartley, W. C., Brown, P. 1942. Experiments on the survival and behavior of the itch mite, *Sarcoptes scabiei* DeG. var. *hominis. Bull. Entomol. Res.* 33:267–71
73. Melton, L. J., Brazin, S. A., Damm, S. R. 1978. Scabies in the United States Navy. *Am. J. Public Health* 68:776–78
74. Moberg, S. A. W., Lowhagen, G. E., Hersle, K. S. 1984. An epidemic of scabies with unusual features and treatment resistance in a nursing home. *J. Am. Acad. Dermatol.* 11:242–44
75. Morrison-Smith, J., Disney, M. E., Williams, J. P., Goels, Z. A. 1969. Clinical significance of skin reactions to mite extracts in children with asthma. *Br. Med. J.* 2:723
76. Munro, J. W. 1919. Report of scabies investigation. *J. R. Army Med. Corps* 33:1–41
77. Nair, B. K. H., Joseph, A., Kandamuthan, M. 1977. Epidemic scabies. *Indian J. Med. Res.* 65:513–18
78. Nair, B. K. H., Joseph, A., Narayanan, P. L., Chacko, K. V. 1973. Epidemiology of scabies. *Indian J. Dermatol. Venereol.* 39:101
79. Nitzulescu, V. 1973. Sur la viviparité possible chez le sarcopte de la gale humaine. *Ann. Parasitol.* 48:355–58
80. Nusbaum, S. R., Drazek, F. J., Holden, H., Love, T. J., Marvin, J., et al. 1975. *Sarcoptes scabiei bovis*—a potential danger. *J. Am Vet. Med. Assoc.* 166: 252–56
81. OConnor, B. 1982. Evolutionary ecology of astigmatid mites. *Ann. Rev. Entomol.* 27:385–409
82. Orkin, M. 1971. Resurgence of scabies. *J. Am. Med. Assoc.* 217:593–97
83. Orkin, M. 1975. Today's scabies. *J. Am. Med. Assoc.* 233:882–85
84. Orkin, M., Maibach, H. I. 1978. This scabies pandemic. *N. Engl. J. Med.* 298:496–98
85. Orkin, M., Maibach, H. I. 1978. Scabies in children. Symposium on Pediatric Dermatology. *Pediatr. Clin. North Am.* 25:371–86
86. Orkin, M., Maibach, H. I., eds. 1985. *Cutaneous Infestations and Insect Bites.* New York: Dekker. 321 pp.
87. Orkin, M., Maibach, H. I., Parish, L. C., Schwartzman, R. M., eds. 1977. *Scabies and Pediculosis.* Philadelphia: Lippincott. 203 pp.

88. Palicka, P., Merka, V. 1971. Contemporary epidemiological problems of scabies. *J. Hyg. Epidemiol. Microbiol. Immunol.* 15:457–61
89. Parish, L. C. 1977. History of scabies. See Ref. 87, pp. 1–7
90. Parish, L. C., Millikan, L. E., Witkowski, J. A., Schwartzman, R. 1983. Scabies in the extended care facility. *Int. J. Dermatol.* 22:380–82
91. Parlette, H. L. 1975. Scabietic infestations of man. *Cutis* 16:47–52
92. Pence, D. B., Casto, S. D., Carley, C. J. 1981. Ectoparasites of wild canids from the Gulf Coastal prairies of Texas and Louisiana. *J. Med. Entomol.* 18: 409–12
93. Pence, D. B., Windberg, L. A., Pence, B. C., Sprowls, R. 1983. The epizootiology and pathology of sarcoptic mange in coyotes, *Canis latrans,* from South Texas. *J. Parasitol.* 69:1100–15
94. Poindexter, H. A. 1978. Scabies. *J. Natl. Med. Assoc.* 70:525–26
95. Pryor, L. B. 1956. Sarcoptic mange in wild foxes in Pennsylvania. *J. Mammal.* 37:90–93
96. Rantanen, T., Bjorksten, F., Reunala, T., Salo, O. P. 1981. Serum IgE antibodies to scabies mite. *Acta Derm.-Venereol.* 61:358–60
97. Reilly, S., Cullen, D., Davies, M. G. 1984. An outbreak of scabies in a hospital and community. *Br. Med. J.* 291: 1031–32
98. Rigatos, G. A., Kappos-Rigatos, I. 1976. Scabies in Greece. *Arch. Dermatol.* 112:1466
99. Rook, A. 1972. Skin diseases caused by arthropods and other venomous or noxious animals. In *Textbook of Dermatology,* ed. A. Rook, D. S. Wilkinson, F. J. Ebling, 1:845–84. Oxford: Blackwell. 1060 pp. 2nd ed.
100. Salo, O. P., Reunala, T., Kalimo, K., Rantanen, T. 1982. Immunoglobulin and complement deposits in the skin and circulating immune complexes in scabies. *Acta Derm.-Venereol.* 62:73–76
101. Sehgal, V. N., Rao, R. L., Rege, V. L., Vadira, S. N. 1972. Scabies: a study of incidence and a treatment method. *Int. J. Dermatol.* 11:106–11
102. Shaw, P. K., Juranek, D. D. 1976. Recent trends in scabies in the United States. *J. Infect. Dis.* 134:414–16
103. Sheahan, B. J. 1974. Experimental *Sarcoptes scabiei* infection in pigs: clinical signs and significance of infection. *Vet. Rec.* 94:202–9
104. Sheahan, B. J. 1975. Pathology of *Sarcoptes scabiei* infection in pigs. I. Naturally occurring and experimentally induced lesions. *J. Comp. Pathol.* 85:87–95
105. Sheahan, B. J. 1975. Pathology of *Sarcoptes scabiei* infection in pigs. II. Histological, histochemical and ultrastructural changes at skin test sites. *J. Comp. Pathol.* 85:97–110
106. Sheahan, B. J., O'Connor, P. J., Kelly, E. P. 1974. Improved weight gains in pigs following treatment for sarcoptic mange. *Vet. Rec.* 94:169–70
107. Shrank, A. B., Alexander, S. L. 1967. Scabies: another epidemic? *Br. Med. J.* 1:669–71
108. Shuster, S., Marks, J. 1967. Dermatopathic anaemia. *Br. J. Dermatol.* 79:393–97
109. Smith, E. B., Claypoole, T. F. 1967. Canine scabies in dogs and in humans. *J. Am. Med. Assoc.* 199:95–100
110. Stamps, T. J. 1969. Scabies in Negroes. *Br. Med. J.* 1:513
111. Stone, W. B., Parks, E., Weber, B. L., Parks, F. J. 1972. Experimental transfer of sarcoptic mange from red foxes and wild canids to captive wildlife and domestic animals. *NY Fish Game J.* 19:1–11
112. Stone, W. B., Tullar, B. F., Zeh, J. B., Weber, B. L. 1974. Incidence and distribution of mange mites in foxes in New York. *NY Fish Game J.* 21:163–66
113. Thomsett, L. R. 1968. Mite infestations of man contracted from dogs and cats. *Br. Med. J.* 3:93–95
114. Todd, A. W., Gunson, J. R., Samuel, W. M. 1981. Sarcoptic mange, an important disease of coyotes and wolves of Alberta, Canada. In *World-wide Furbearer Conf. Proc.,* ed. J. A. Chapman, D. Pursley, pp. 706–29
115. Trainer, D. O., Hale, J. B. 1969. Sarcoptic mange in red foxes and coyotes of Wisconsin. *Bull. Wildl. Dis. Assoc.* 5:387–91
116. Van Neste, D., Lachapelle, J. M. 1981. Host-parasite relationship in hyperkeratotic (Norwegian) scabies: pathological and immunological findings. *Br. J. Dermatol.* 105:667–78
117. Van Neste, D., Mrena, E., Marchal, G. 1981. Le cycle evolutif du *Sarcoptes scabiei* (var. *hominis*): une etude en microscopie electronique a balayage. *Ann. Dermatol. Venereol.* 108:355–61
118. Van Neste, D., Salmon, J. 1978. Circulating antigen antibody complexes in scabies. *Dermatologica* 157:221–24

119. Witkowski, J. A., Parish, L. C. 1978. Scabies update 1978. *Int. J. Dermatol.* 17:401–2
120. Woodley, D., Saurat, I. 1981. The burrow ink test and the scabies mite. *J. Am. Acad. Dermatol.* 4:715–22
121. Wooten, E. L., Gaafar, S. M. 1984. Detection of serum antibodies to sarcoptic mange mite antigens by the passive hemagglutination assay in pigs infested with *Sarcoptes scabiei* var *suis*. *Vet. Parasitol.* 15:309–16
122. Wooten, E. L., Gaafar, S. M. 1984. Hemagglutinating factor in an extract of *Sarcoptes scabiei* var. *suis* (De Geer). *Vet. Parasitol.* 15:317–23